SPC 96-4026 **ADDENDUM** Contract F61708-96-W0246

BASED ON INVITED LECTURE

«GAMMA-RAY SOLID LASER: AMPLIFICATION WITHOUT INVERSION AND MICROPLASMA OF ACTIVE MEDIUM. SOME RESULTS IN SUBSTANTIATION FOR A FEASIBLE γ-LASING EXPERIMENT»

which was reported at the International Conference «Laser optics'98» 22-26 JUNE 1998, St. Petersburg, Russia and Published in the Proceedings of SPIE, vol. 3685, pages 167 - 176.

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CONTENT

FOREWORD.

F1. During the last two decades (1979-1999) the so called Softening Complex for the Gamma-Lasing is growing. This Complex is developing slowly but permanently and steadily as a certain tree. The Main Present Branch of that Tree called as SPTEN (Soft Prompt Transplantation of the Excited Nuclei) is outlined in the Addendum.

F2. The SPTEN's apparition is not sudden. It has many precursors. Many ideas, analytical and critical works on γ-laser items and on the adjacent fields of science and technique facilitated the way to the SPTEN. The Author is very appreciative to its Authors as like as to his Old Good Teachers. Especially to those who spend the time for the discussions. So the SPTEN organically joints great manifold of the scientific and trial ideas and results.

F3. SPTEN joints differ ideas, methods and theories on base of One Single Program. The Main Principle of that Program is a Feed Back Conception about mutual links in a total complex of beneficial and adverse processes in Real γ-Laser. In result the merits of all adopted ideas enhance each other. But all adverse processes and hindrances resident in that ideas are suppressed. Indeed SPTEN divides, isolates and in a such manner suppresses all its hindrances but it joints the beneficial sides of adopted ideas with its mutual enhance.

F4. SPTEN-γ-Laser can do without use of Hyper Fine Structure in the site of the Active Medium.

F5. SPTEN-γ-Laser can do without use of any External Fields (Laser, Radio-Frequency, Static, etc.) in the site of the Active Medium for the line narrowing.

F6. SPTEN-γ-Laser can do without use of any fields in the site of the Active Medium for the creation of the inverse population.

F7. SPTEN-γ-Laser can do without use of any fields in the site of the Active Medium for the creation of so called Amplification Without Inversion.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	20 December 1999	Final Report

4. TITLE AND SUBTITLE

Gamma-Ray Solid Laser: Amplification without Inversion and Microplasma of Active Medium.

5. FUNDING NUMBERS

F6170896W0246

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

EOARD
PSC 802 BOX 14
FPO 09499-0200

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

SPC 96-4026

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT (Maximum 200 words)

This report results from a contract tasking Russian Academy of Sciences as follows: The contractor will identify and evaluate nuclei that may be used in the straight experimental demonstration of gamma-laser oscillations as described in his proposal.

14. SUBJECT TERMS

EOARD, Lasers

15. NUMBER OF PAGES

13

16. PRICE CODE

N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19, SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

F8. SPTEN creates the most favorable conditions for the cooling of Active Medium at the period of both the pumping and the γ-lasing.

F9. Active Medium at SPTEN-pumping is an Unusual Medium. It is a **Hybrid** of ***Cold*** *Solid Host-Lattice* with the ***Hot*** *Non-Equilibrium Light Micro-Plasma*. $T_{\mathbf{host}} < 30$ K, $T_{\mathbf{micro\text{-}plasma}} > 30\,000$ K.

F10. It leads to the natural transforming of the inhomogeneous wide-band Moessbauer spectrum into only one distinct narrow line .

F11. Hence it is no ever branching that is very beneficial for the γ-lasing.

F12. The main input part of the SPTEN is the so called Multi Beam Emitter (MBE), which creates well oriented and powerful Multi Beam of atoms or ions with the Excited Nuclei. The Multi Beam contains a big amount ~ 10^8 of ordinary beams (so called microbeams), which are mutually exactly paralleled. The MBE can be applied distinctly without a γ-laser. And it is very probable that MBE would be created long before than its «parent», i.e. the γ-laser.

F13. The main merit of SPTEN is its possibility to be very variable, to do with many nuclei and hosts, to do with many sources, to do as a hybrid with many other γ-laser types, to simulate other γ-laser types before its realization.

F14. SPTEN holds many other merits and properties. Some its part is regarded in the Present Work and in its Addendum.

F15. *The SPTEN needs be widely declared and discussed. Because even if only a small part of all above is a truth then it leads to the very serious changing in the Present Status of Gamma-Laser Problem, viz.,*
– The rise of the SPTEN-direction would then mean that:
– 1. The Gamma-Laser Creation HAD BEEN TRANSFERRED
FROM the Category of the Principally Non-Resolved Problems
INTO the Category of the Feasible Indeed but Very Complex Technology Tasks.
– 2. The many-decades Stage Devoted to the Negotiation of the Principal Difficulties' Complex in Gamma-Lasing Creation IS FINISHED.
– 3. The next Stage of the Scientific-Engineering Elaboration and the Technology Preparation for the Indeed Realized Direct Trials with the Immediate Detecting of the Gamma-Lasing IS OPEN.

F15.Russian. *Необходимо широкое обнародование и обсуждение SPTEN. Потому что,* ***если даже только небольшая часть вышесказанного подтвердится,***
то это приведет к серьезным изменениям
в ныне существующем состоянии дел в проблеме гамма-лазера, а именно,
- Появление SPTEN тогда бы означало, что:
- 1. Создание Гамма-Лазера ПЕРЕШЛО
ИЗ Категории Принципиально Нерешенных Проблем
В Категорию Осуществимых На Деле, но Очень Сложных Технологических Задач.
- 2. Длившийся десятилетиями Этап Преодоления Комплекса Принципиальных Трудностей ЗАВЕРШЕН.
- 3. ОТКРЫВАЕТСЯ Этап Научно-Технической Разработки и Технологической Подготовки На Деле Реализуемых Прямых Экспериментов с Непосредственным Детектированием Гамма-Лазерной Генерации.

F16. But a pair of Big «No» exists.

The first «No» is that MBE and SPTEN are yet created only at the paper. And it needs very long period for its realization indeed. It is the truth. And hence the theorists have some years in order to check each element of MBE and SPTEN by different means before the experiments. One of such checking is the Present Work of the Author devoted to the use of Photonuclear reactions in the SPTEN.

The second «No» is that these methods are very complex already yet now. And these methods will become else more complex. Because its will be covered by some layers of the specialty of the next order.

It is the well known south that each new answer leads to the new envelope of the sub-problems of the next generation. But it is not a lack of the SPTEN. Vice versa it is a big merit of the SPTEN. Because it is the apparent argument of that the SPTEN method is growing, developing and conquering all new difficult questions on its way to the real experiment. Already yet more than twenty years the SPTEN stands the all-round checking by the time lapse.

F16.Russian. Однако, существуют два Больших «Но».

Во-первых, MBE и SPTEN созданы пока только на бумаге. И до их реализации в эксперименте пока очень далеко. И это действительно так. Значит, у теоретиков есть еще несколько лет, чтобы основательно проверить каждый элемент в SPTEN, прежде чем начнутся эксперименты. Одной из таких проверок является Настоящая Работа Автора, посвященная использованию Фотоядерных реакций в SPTEN.

Во-вторых, эти методы очень сложны уже сейчас. И эти методы станут еще сложнее. Потому что они обрастут несколькими слоями подробностей, соответствующих преодолению трудностей следующих порядков. Связано это с известной истиной о том, что каждый ответ при решении сложной проблемы порождает множество новых вопросов, т.е., каждый комплекс ответов порождает новый слой проблем следующего порядка. Но это не недостаток, а достоинство модели SPTEN, т.к. это есть бесспорное доказательство того, что она растет, развивается, преодолевая все новые и новые вопросы и трудности на своем пути. Уже более двадцати лет SPTEN выдерживает всестороннюю проверку временем.

F17. The Present Work is based on a row of fundamental works. It is based particularly on two Invited Lectures:
I. The Invited Lecture at the First International Workshop on the Induced Gamma Emission, Predeal-Garalas'97: **S.V.Karyagin,** «Gamma-Ray Solid Laser: Line Narrowing in Self Micro-Plasma, Steadiness against both the Self-Radiation Defects and Self-Heating» referred in Present Work as [32].
and
II. The Invited Lecture at the International Conference on the Fundamental Problems of Laser Optics'98 (LO'98), St. Petersburg: **S.V.Karyagin,** «Gamma-Ray Solid Laser: Amplification Without Inversion and Microplasma of Active Medium. *Some Results in Substantiation for a Feasible γ-Lasing Experiment*» referred in Present Work as [35].

This **Second Lecture** contains the main results of the first one. Besides the Second Lecture
- introduces the very perspective novel candidate 58Co;
- constructively analyses the SPTEN-class;
- constructively analyses the OTHER CLASSES at the comparison with the SPTEN;
- revises and modernizes the induced and super-radiant emission theories.

On this base just exactly the Second Lecture is adopted as the Addendum for the Present Work. This Addendum is differ from the simple copy of the Ref.[35] because in the Addendum
- some errata (especially in the formulas) are corrected;
- some vague phrases are changed or are detailed.

Ref.[32]. S.V. Karyagin, 1997, "Gamma-ray solid laser: line narrowing in self micro-plasma, steadiness against both the self-radiation defects and self-heating", 1st International Induced γ-Emission Workshop, Predeal, Romania, August 16-20, Techn. Digest(1997)97. Published in Ref.[16], p.p.120-137.

Ref.[35]. S.V. Karyagin, 1998, "Gamma-ray solid laser: amplification without inversion and microplasma of an active medium. Some results in substantiation for a feasible gamma-lasing experiment." – Intern. Conf. "Fundamental Problems of Laser Optics (Laser Optics'98)", 22 - 26 June 1998, St. Petersburg, Russia. published in Proc. SPIE (Intern.Soc. for Optical Engineering), ed. by N.N.Rosanov, vol. 3685, 167-176.

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Gamma-ray solid laser: amplification without inversion and microplasma of active medium

Some results in substantiation for a feasible γ-lasing experiment

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ABSTRACT

Some results in substantiating for a *feasible γ-lasing experiment* are considered. *Self microplasma (SM) existence* in active medium (*AM*) is set up. *SM*-density at other pumping types is more by several orders than one at *soft prompt transplantation of excited nuclei* (*SPTEN*). Hence schemes of *amplification without inversion* (*AWI*) are broken down by the *SM*. Types of *AWI and γ-lasers steady against SM* are revealed. "*Width-path effects*" *(L'-effects)* on Moessbauer spectrum and on a γ-lasing are predicted. *Radiation-heat regimes and γ-lasing conditions (induced, super-radiant)* are studied. Difficulties of gas-*AM* (in beams) are analyzed. *New candidate ^{58}Co (28.1 keV, 1.51 10^{-5} s)* is suggested. Efficiency of *SPTEN* and *industrial laser isotope separation* can be drastically increased on base of proposed so called "*atomic (molecular) multi-beam emitter*".

Keywords: *gamma-ray solid laser, cooling of active medium, isomeric transitions, quantum nucleonics, selective resonant pumping, amplification without inversion, Borrmann effect, collapse of Moessbauer spectrum by motion of charged carriers*

1. INTRODUCTION

From early works (1961,Rivlin; 1963,Baldwin et al.) up to nowadays a big world experience in *γ-laser* (*GL*) is stored. A crisis in *GL*-problem was happened just before 1980-th: no real nuclei-candidates, "heat death" of *GL*, etc. That crisis stimulated creation of a hybrid model[1-9] on joint of a row *GL*-directions adopted with all world *GL*-experience account. In works[1-9] and here a feasible model of **gamma-ray solid laser** *on short-lived isomers* using a method of so called *soft prompt transplantation of excited nuclei* (***SPTEN***)[3-9] is developed. Active medium (***AM***) is creating during the short time of isomer-implantation with kinetic energy of ions less than *0.5 keV*. So the *AM* is created with list heating and negligible substrate destruction. Theory and computer simulation show[3,5,6,9,19] that just after such pumping a big density of *excited lasing-active nuclei* (***ELAN***) $n_+ > 10^{21} cm^{-3}$, a high relative population $n_+/n > 0.9$ and more than sufficient amount of *ELAN* $N_+ = n_+V_{AM} > 10^{13}$ in active medium *(AM)* of volume $V_{AM} \sim 10^{-8} cm^3$ could be reached. At *SPTEN* an existence of resolved hyperfine structure (***HFS***) for working transition is not necessary. Moreover, a collapse of *HFS* (see **1.6**) is beneficial for *γ-lasing*[1-5,7].

1.1 Candidates for gamma-ray solid laser

This model[1-9] is able to use a plenty of different working nuclei-candidates arisen in many reactions, including photo-processes, non-elastic (e.g., Coulomb) scattering of particles on parent nuclei, non-elastic (e.g., Coulomb) scattering of parent nuclei passed through crystal, particle-exchange, etc. Widely known *nuclide* ^{181}Ta is only the most studied "satisfactory" candidate. However even such candidate answers all *in situ* and *ex situ* demands of a real experiment[3-7].

Here a new candidate "^{58}Co" is suggested. In this case a <u>working transition</u> (WT) has energy $E_\gamma = 28.1$ keV; wave-length $\lambda = 4.41\ 10^{-9}$ cm. Time-life (decaying by factor $e^{-1} = 0.368$) $\tau_1 = 1.51\ 10^{-5}$ s. Internal conversion coefficient $\alpha = 1.5$. In diamond matrix (diamond of IIa-type) Debye temperature $T_D = 1860$ K. <u>Case of ^{58}Co in diamond is marked as ^{58}Co/Di.</u> At temperatures $T << T_D$ a factor of recoilless emission $f' = 0.86$. Both working levels (WL), upper "+" and lower "-", are excited. Branching ratio of WT is $w = 0.999$. Adopted here time-ratio $\tau_1/\tau_2 = 1.1$. A total width of WT $\tau_2^{-1} = \Gamma_{tot}$ is "effected by distance", see **2.1**. Nuclear moments of WL are $j_+ = 4^+$ and $j_- = 5^+$. The time-life of lower WL is $\tau_- = 4.78\ 10^4$ s. The time-life of ground state is $\tau_{gr} = 8.83\ 10^6$ s. The ratio of statistical weights $g = (2j_+ +1)/(2j_- +1) = 9/11 = 0.818$. Conventional resonant cross-section (at ratio $\tau_1/\tau_2 = 1$, in a frequency-maximum, without HFS) is $\sigma_0 = 1.1\ 10^{-18} cm^2$. Conventional cross-section of resonant self-absorption $\sigma_{sa} = g\,\sigma_0 = 8.75\ 10^{-19}$ cm^2. Cross-section of self non-resonant losses on Co-atoms $\sigma = 1.2\ 10^{-21} cm^2$. Cross-section of non-resonant losses on C-atoms of diamond $\sigma' = 5.63\ 10^{-24}$ cm^2. Exited laser-active nuclei (ELAN) ^{58}Co* could be created (as recoiled nuclei) in so called "converters"[3-5], e.g., at reactions ^{58}Ni(n,p)^{58}Co* or ^{59}Co(n,2n)^{58}Co* with cross-section $\sigma^* = (0.5 - 0.8)\ 10^{-24}$ cm^2. Even at such small value of σ^* the SPTEN can fit $\mathbf{N_{max}} \sim 10^{13} - 10^{14}$ of ELAN at AM site[3-9]. There are many types of AM-body forms[2]. The simplest one has a quadrate in its cross-section with a side **d**, and a length L. AM has dispersed micro-profile (see **1.4**) with external (visible) volume $d \times d \times L$. Let concentration of working nuclei (WN) is $\mathbf{n} = 9\ 10^{20} cm^{-3}$, its total number $N_o = 2\ 10^{11} << N_{max}$ and content of ELAN at the initial moment is 0.9. Then a length of AM is L = 0.32 cm, d = 3.8 10^{-5} cm, and AM gives 2.5 10^7 induced gamma-quanta (see **2.1**). The portion of super-fluorescent gamma-radiation in this case is negligibly small (see **2.2**). The heat release in this AM is

$$q = n\, E_\gamma\, \alpha /((1+\alpha)\ \tau_1) = 1.6\ 10^{11}\ W/cm^3. \qquad (1)$$

At these conditions the self-consistent method *gives the estimation $T_{AM} = 27.3$ K for the* quasi-temperature[2,4] *of AM. Such low temperature is oblige to the fulfillment of the* condition for efficient cooling

$$\Lambda_e,\ \Lambda_{ph} >> d. \qquad (2)$$

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where values Λ_e, Λ_{ph} are the free paths of non-equilibrium electrons and phonons correspondingly. Indeed, for the diamond of II-a type at 27.3 K the free paths are $\Lambda_e = 8.5\ 10^{-4}$ cm = 22.4 d >> d , $\Lambda_{ph} = 0.028$ cm = 737 d >> d.

1.2 Balance energy equations for AM, self-consistent method

Balance energy equations for AM (1983,1995, Karyagin) were derived and used in works[2-5,7]

$$(d/dt)Q_e = q - (\tau_{ep}^{-1} + \tau_e^{-1})Q_e\ , \qquad (3a)$$

$$(d/dt)Q_{ph} = -\ \tau_{ph}^{-1}\ Q_{ph} \quad + \tau_{ep}^{-1}\ Q_e\ , \qquad (3b)$$

$$q = 1.6\ 10^{11} W/cm^3\ ,\ \tau_e = 3.8\ 10^{-13}\ s\ ,\ \tau_{ph} = 2\ 10^{-11}\ s, \qquad (4)$$

where Q_e is energy-density (ED) of non-equilibrium (NE) charged carriers, Q_{ph} is the ED of NE-phonons; $\tau_e = d/v_e$ is time of free exit of charged NE-carriers from AM; $\tau_{ph} = d/v_s$ is a time of free exit of NE-phonons from AM; $v_e \sim 10^8$ cm/s is a mean velocity of charged NE-carriers with energy ~ 1 – 5 eV. For a diamond of II-a-type[18] sound velocity is $v_s \sim 1.6\ 10^6$ cm/s. Time of electron-phonon relaxation τ_{ep} is found from a trial electron-hole mobility[18] $\mu = e\tau_{ep}/m \sim 1.8\ 10^{15}\tau_{ep}$. Here μ is used in $cm^2V^{-1}s^{-1}$ and τ_{ep} in seconds. The decisions for (3a,b) are (5a,b) or (6a,b), (7) in a stationary limit $t >> \tau_{ep}, \tau_e, \tau_{ph}$:

$$Q_e = (q/(\tau_{ep}^{-1} + \tau_e^{-1}))(1 - \exp(-(\tau_{ep}^{-1} + \tau_e^{-1})t)), \tag{5a}$$

$$Q_{ph} = (q\tau_{ph}/(1+(\tau_{ep}/\tau_e)))\{1 - \exp(-t/\tau_{ph}) - [[\exp(-t/\tau_{ph}) - \exp(-(\tau_{ep}^{-1} + \tau_e^{-1})t)]/[(\tau_{ep}^{-1} + \tau_e^{-1})\tau_{ph} - 1]]\}, \tag{5b}$$

$$Q_e = q/(\tau_{ep}^{-1} + \tau_e^{-1}), \tag{6a}$$

$$Q_{ph} = q\tau_{ph}/(1 + (\tau_{ep}/\tau_e)). \tag{6b}$$

$$Q_e = 0.051\ \mathrm{J/cm^3},\quad Q_{ph} = 0.012\ \mathrm{J/cm^3}. \tag{7}$$

The values (7) are achieved by the *self-consistent method*[2,4,7]. The value τ_{ep} is a function[18] of a quasi-temperature[4] $T = T_{AM}$ which at $T << T_D$ is proportional to $Q_{ph}^{1/4}$ with the factor 82.1 K for diamond[4] (Q_{ph} and T are taken in J/cm^3 and K):

$$\tau_{ep}(T) = \tau_{ep}(50\ K)(50/T)^{1.5} = 3.4\ 10^{-11}(50/T)^{1.5}\ s = 1.2\ 10^{-8}\ T^{-1.5}\ s, \tag{8}$$

$$T = 82.1\ (Q_{ph})^{1/4}. \tag{9}$$

Substitution (8), (9) into (6) gives non-linear equations, which lead to self-consistent results (7) - (10):

$$T = 27.2\ K,\quad \tau_{ep} = 8.5\ 10^{-11}\ s \text{ and mobility } \mu = 1.5\ 10^5\ cm^2\ V^{-1}s^{-1}. \tag{10}$$

A more accurate procedure with the self-consistent accounting of non-equilibrium carriers in the rest part (around the AM and further) of previously cooled crystal (T~10K) leads to a more precise estimation of quasi-temperature $T = T_{AM}$ in AM

$$T_{AM} = 27.3\ K. \tag{10a}$$

Good coincidence of results (10) and (10a) shows accuracy of simple equations (3), (3a) when condition (2) is fulfilled. *An active medium of solid cold γ-laser contains a self-microplasma* (1995,Karyagin). The existence of self-microplasma was first predicted and theoretically set up in works[4,7]. A density of charged carriers n_e is set at *energy for the creation of pair of charged carriers* ε_0 (13.3 eV = 2.1 10^{-18} J for diamond[18]):

$$n_e = 2\ Q_e/\varepsilon_0 = 4.8\ 10^{16}\ cm^{-3}, \tag{11}$$

So, it is proved that the gamma-generation is not suppressed by heat *in case of SPTEN.* Besides it is shown[5,7] (also see **1.6**) that **appearance of self-microplasma is beneficent for a gamma-lasing in SPTEN-schemes.**

1.3 Suppression of inhomogeneous Doppler shift in solid AM by a "heat-stress-feedback method"

A *solid* AM differs from active media of other aggregate states by a feasibility of method[1-3] (1980,Karyagin) for the full suppression of the inhomogeneous Doppler shift (IDS). The IDS results from a heat expansion of AM[10] and makes a γ-lasing non-realized. Suggested method[1-3] consists in a preliminary moderate stress (stretch, compression) of AM-body *fasten by the thermostated fixtures.* In such conditions any deviation in forces due to the temperature is exactly compensated by the opposite prompt deviation of fixture stress-reaction. Otherwise, in method[1-3] a deep feedback through the fixture stress-reaction is used. The use of "heat-stress feedback method" in other aggregate states is too problematically.

1.4 Developed oriented (e.g., comb-like) micro-profile (DOCLMP) of AM for effectiveness of all solid γ-laser types

Developed oriented (e.g., comb-like) micro-profile (DOCLMP) of AM was suggested and elaborated[2,3-5,7] (1983, 1995, Karyagin) for the effective cooling of AM. E.g., DOCLMP can be engraved on surface of single-crystal as line row of teeth. Each tooth is characterized by transversal width d , transversal high (or depth) h and longitudinal size (thickness) d_o. A size d_o is measured at half of a high h. Hence the thickness at the bottom (foot) of tooth is $2d_o$. The distance between the tops of two nearby teeth (period of DOCLMP along active medium) is $2d_o$. Fulfill number of teeth is $N_{th}=L/2n_o$. E.g., in considered case (see**1.1**) L= 0.32 cm, d = h = 3.8 10^{-5} cm, d_o = 10^{-6} cm, N_{th} = 1.6 10^5 and a fractaility (denticulation) is $h/2d_o$ = 19. A building of such DOCLMP demands to use modern micro and nano technologies.

Owing to DOCLMP *the demands to pumping, g-lasing and cooling (energy transfer from AM to crystal-substrate) are in compromise.* In deed in order to avoid diffraction losses it is necessary to have AM with diameter $(\lambda L)^{1/2} \sim 10^{-4}$ cm. Intrusion of heavy atoms to *depth* 10^{-4} cm is possible only in a *hard intrusion* at energies 10^6 – 10^7 eV. A heat release in such case is more by 2 – 4 orders than q = 1.6 10^{11} W/cm^3 in eq.(1). *Owing to* DOCLMP *it is possible to coincide a soft transplantation in* 1 – 5 *outer surface layers (at energy* ~ 10^2 eV*) with a sufficiently big transversal size of AM* ~ 10^{-4} cm. A density of heavy atoms n = 9 10^{20} cm^{-3}, see 1.1, leads to strong scattering of *energy carriers* (EC) and so to decreasing of paths Λ_e , Λ_{ph} (see eq.(2)) lower than 10^{-6} cm. Fortunately all working nuclei are sited at near-surface layers (boundaries of DOCLMP) and so its doesn't hinder to free exit of EC (phonons, electrons, holes) from AM. So *owing to* DOCLMP *the paths* Λ_e , Λ_{ph} *are the same as without impurities.* Lastly, a big ratio $d/2d_o \sim 50$ leads to a big distances ~ 3 10^{-7} between

near-hood working nuclei and so DOCLMP is beneficial for line narrowing. DOCLMP is necessary element for a construction of AM in all (not only SPTEN) solid γ-lasers. More common types of DOCLMP are regarded in work[2].

1.5 Atomic (molecular) multi-beam emitters (MBE)

A more than sufficient amount of ELAN and its density in AM could be reached with help of a specific device (1983,1995, Karyagin) called as "converter" for γ-lasing or as atomic (molecular) "multi-beam emitter" (MBE) for some other scientific and practical applications[3,5,6,19]. Owing to these devices with oriented deep micro-relief[3,5,6,19] the effectiveness of laser isotope (isomer) separation (LIS)[33,34] can be increased by some orders at keeping of LIS-quality. Such result for MBE is owed to: big amount of atoms in multi-beam, preliminary its cooling and de-ionization, possibility to clean beam from ions before switch the LIS, weakening of both charge exchange probability and Doppler spread, compactness of device. Besides: the efficiency of LIS increases extremely by many orders if isotopes (isomers) are born in surface layers of MBE. At this case not only stable isotopes but also short-lived isomers can be more successively separated by laser. The know-haw and some equipment for MBE-development are available in Semenov Institute.

1.6 Narrowing effect of self-micro-plasma on γ-lasing in SPTEN-schemes

Free *charged carriers* (CC) are jumping between the host atoms with frequency $\nu' \approx \nu_e (n')^{1/3} \approx 10^{16}$ s^{-1}. The CC are trapped by working atoms. Two types of working traps are interesting: 1. – Deep traps with a long time-living t_{tr} of trapped CC, i.e., $t_{tr} >> 1/\nu'$; 2. – Fine traps, when $t_{tr} \sim 1/\nu'$. In case of deep traps of only one type a line broadening can be small and $\Gamma\tau_1 \approx 1$, if homogeneity of crystal-chemical parameters[15] of trap environment exists at going overall AM from trap to trap. **In case of many trap-types the spectrum is dispersed over many peaks** multiplied by a number of HFS-peaks. Together with relaxation processes it gives a continuos spectral band with a damping factor $\Gamma\tau_1 >> 1$ adverse for γ-lasing. In case of fine traps the **working atoms are recharging,** i.e., its charge-state are changing through "+", "0", "-" with a frequency $\nu_r = n_e \nu'/n'$. The line depends on the charge-state of trap and so is running through positions ω_+, ω_o, ω_- with an amplitude $\delta = \sup\{|\omega_+ - \omega_o|; |\omega_- - \omega_o|; |\omega_+ - \omega_-|\}$. If $\delta << \nu_r$, then one single line of a width $\Gamma = \tau_1^{-1} + \Delta\Gamma$ arises instead of "triplet" ω_+, ω_o, ω_-. Here $\Delta\Gamma \approx \delta^2/\nu_r \approx (\delta^2\ n'^{\,2/3}) / (2n_e\nu_e)$. The broadening $\Delta\Gamma$ can be decreased by the selection of AM (nucleus, substratum) or by regulation of heat-radiate regime, through the changing parameters δ, n', $n_e \sim n_+ d$. At case of a fortunate selection of AM or its parameters *it could be reached* **the effect of spectral "collapse", i.e., the contraction of all lines of an inhomogeneous spectrum with its HFS into one tight singlet with a natural width $\Gamma\tau_1 \approx 1$. This effect is beneficial for γ-lasing, especially in cases $\tau_1 \sim 10^{-4}$c, $\tau_1 > 10^{-4}$c** (but not for too big τ_1). *This narrowing effect was verified.* E.g., in the low-temperature samples (saturated with hydrogen) the narrowing of lines and its collapse into narrow singlet were revealed when temperature was increasing[13].

E.g., for AM of type ^{58}Co/Di at $T_{AM} = 90$ K the appropriate values are: $n_e \approx 5\ 10^{18}$ cm^{-3}; $\nu' \approx 10^{16}$ s^{-1}; $\nu_r = n_e \nu'/n' \approx 3\ 10^{11}$ s^{-1}. Let $\delta =$ 6.3 10^7 s^{-1}, then $\Delta\Gamma = \delta^2 / 2\nu_r =$ 6.7 10^3 s^{-1} $= 0.1\ \tau_1^{-1}$. A *spectral band* of width $\delta = 6.3\ 10^7$ s^{-1} (without plasma) is collapsed into *single line* of width $\tau_1^{-1} + \Delta\Gamma$, where $\Delta\Gamma = 6.7\ 10^3$ s^{-1} (at micro-plasma). Another words, a spectral band with adverse factor $\tau_1\delta = 958$ is collapsed into line of natural width with a broadening factor $\tau_1\Delta\Gamma = 0.1$. So $\tau_1/\tau_2 = 1.1$, see ch.**2**.

2. REAL GAMMA-LASING CONDITIONS

2.0. Effects of distance on γ-lasing or alias the «Width-Path Effects» (WPE) or alias «*L'-effects*». For the initial stage at $t << T_2$ amount of γ-quanta in a lasing mode is small, a phase is absent, propagation of photons could be regarded separately from others and a total spectral width Γ_{tot} in γ-lasing mode is (*width-path effects*, *WPE*, see **2.1**, **2.2**)

$$\Gamma_{tot} \equiv \tau_2^{-1} = \Gamma + \Gamma(L', \tau_v)\,,\ \Gamma(L', \tau_v) = (\tau_v + L'/c)^{-1}. \tag{12}$$

Here $\Gamma = \Gamma_h + \Gamma_{ih}$ is a standard total width, $\Gamma_h + \Gamma_{ih}$ is a sum of homogeneous Γ_h and heterogeneous Γ_{ih} widths[15,16]. A term $\Gamma(L', \tau_v)$ depends on free path of photon L'. Path L' is a length along eikonal of photon from place of its arising to a place of its exit from a lasing mode. A *photon is vanishing for a time* τ_v in resonant or non-resonant absorption and scattering. For resonant processes $\tau_v \sim \Gamma^{-1}$; for non-resonant ones $\tau_v << \Gamma^{-1}$. A sum $\tau_\gamma = \tau_v + (L'/c)$ is a "time-life" of photon in lasing mode. In rise only $1/\Gamma_{tot}\tau_{rad}$ of photons induce emission. All resonant probabilities must to include "filtering factor"(see **2.1**,**2.2**)

$$1/\Gamma_{tot}\tau_{rad} = \tau_2/\tau_{rad} = (\tau_2/\tau_1) f' w/(1+\alpha), \tag{13}$$

A vanishing of photon (not only in a detector) interrupts any interaction with it for the time τ_γ that is accounted in γ-lasing not only through the "filtering factor"(*width-path effects*, *WPE*, see **2.1**, **2.2**).

The **time $\tau_2 = 1/\Gamma_{tot}$ is less than standard time $T_2 = 1/\Gamma$** (which is used widely) because always $\Gamma_{tot} > \Gamma$. *In optic lasers* due to n-fold reflection of photon by mirrors the normal sizes of optical device are sufficient to have $L' > 10cT_2$ and so $\Gamma < 0.1\Gamma_{tot}$, $\tau_1/\tau_2 > 1.1$. But at non-resonant detector in *mirror-less γ-laser* $\Gamma < 0.1\Gamma_{tot}$ only at *long distance $L' > 10\tau_1 c$ between its exit-plate of γ-laser and the detector (or absorbing target)*. E.g., $\tau_1/\tau_2 > 1.1$ for ^{58}Co if a distance $L' > 4.5\ 10^6\ cm = 45\ km$.

These "*width-distance effects*" (*L'*-effects, Width-Path Effects) are accounted below in sec.2.1, 2.2. *In Moessbauer effect experiments* a vanishing time is $\tau_v \sim \tau_1$ due to big duration of resonant absorption (scattering)[28]. So $L' > \tau_v c$ in other to observe the L'-effect on

line width. Deformation of line-form by apparatus depends on a distance L' too. So $\Gamma = \Gamma_{ob}(L') - \Gamma_{ap}(L') - \Gamma$, where $\Gamma_{ob}(L')$ is an observable line width, $\Gamma_{ap}(L')$ is apparatus broadening, and *a "subtraction" indeed is the deciding of* rolling-type *equation*

$$I_{ob}(\omega) = \int_0^{\infty} I(\omega')\, A(\omega-\omega')\, d\omega'. \qquad (14)$$

I.e., to execute in deal subtraction $G_{ob}(L') - G_{ap}(L')$ means to find a true (non-deformed) form of Moessbauer line $I(\omega')$, if the form $I_{ob}(\omega)$ and kernel $A(\omega-\omega')$ are the well-known functions of frequency ω. Here $I_{ob}(\omega)$ is the observable line-form and the kernel $A(\omega-\omega')$ is the apparatus function. A more general form than equation (14) is a linear integral transformation

$$I_{ob}(\omega) = \sum_{e}\sum_{e}\iiint_{r}\iiint_{r'}\iiint_{k}\iiint_{k'}\int_{\omega'} \rho(\mathbf{r}')\, I(\mathbf{r}',\mathbf{k}',\mathbf{e}',\omega')\, A(\mathbf{r},\mathbf{r}';\mathbf{k},\mathbf{k}';\mathbf{e},\mathbf{e}';\omega,\omega')\, \mathbf{d^3r}\, \mathbf{d^3r'}\, \mathbf{d^3k}\, \mathbf{d^3k'}\, d\omega', \qquad (15)$$

where $\mathbf{r}'$ is start point of emitted photon in source; $\mathbf{r}$ is finish point of this photon in detector; $\mathbf{k}', \omega', \mathbf{e}'$ are start values (in source) of wave vector, frequency and polarization correspondingly ; $\mathbf{k}, \omega, \mathbf{e}$ are the final (in detector) ones; $\{\mathbf{e},\mathbf{e}';\ \mathbf{r},\mathbf{r}';\ \mathbf{k},\mathbf{k}';\ \omega'\}$ is a region of integration; $\mathbf{d^3r} = dx\, dy\, dz$; $\mathbf{d^3r'} = dx'\, dy'\, dz'$; $\mathbf{d^3k} = dk_x\, dk_y\, dk_z$; $\mathbf{d^3k'} = dk'_x\, dk'_y\, dk'_z$; $\mathbf{r} = (x,y,z)$ is radius-*vector* $\mathbf{r}$ with components x, y, z of final point of photon in detector; $\mathbf{r}' = (x', y', z')$ is radius-vector $\mathbf{r}'$ of start point of photon in source: kernel $A(\mathbf{r},\mathbf{r}';\mathbf{k},\mathbf{k}';\mathbf{e},\mathbf{e}';\omega,\omega')$ is not symmetric to the permuting in pairs $\mathbf{r} \Leftrightarrow \mathbf{r}'$; $\mathbf{k} \Leftrightarrow \mathbf{k}'$; $\mathbf{e} \Leftrightarrow \mathbf{e}'$; $\omega \Leftrightarrow \omega'$ and is not a function of only differences $\mathbf{r} - \mathbf{r}'$; $\mathbf{k} - \mathbf{k}'$; $\mathbf{e} - \mathbf{e}'$; $\omega - \omega'$. Kernel $A(\mathbf{r},\mathbf{r}';\mathbf{k},\mathbf{k}';\mathbf{e},\mathbf{e}';\omega,\omega')$ is a general apparatus functional which is depended on both : on the self-apparatus properties and on all interactions of photons with media along its eikonals.

The transformation of rolling-type (14) can only to broaden natural line, but it can't to narrow line $I(\omega')$. In contrary to it a general **transformation (15) can make** both: **to narrow** and to broaden **form of line**. In deal, a line more narrow than natural one could be got in n-fold Bragg resonant scattering, at some superposition of resonant filters, or in case of amplification. So, there are **yet no evidence for a new effect**[23] even if observable line $I_{ob}(w)$ is more narrow than a natural one[24]. The width-path effect (12) doesn't change the spontaneous time τ_1. But it needs be accounted in analyses of γ-lasing (see **2.1**, **2.2**) and some trials[21–26]. A significant part of "shielding-effects" *(SE)*[23–25] can be conditioned or masked by *L'-effect* (12) and by a disregarding with a general relation (15). Note two remarks: **1.** – A zero-field-nucleus interaction can't to change essentially an internal electron conversion probability. So a new "shielded"[23–25] natural time-life τ_l' can't be more than $(1+\alpha)\tau_l/\alpha$. **2.** – In a strict quantum theory any real value (e.g., width) needs to be invariable to orthogonal normalized (*ON*) changes in *ON* complete base of self vectors (functions, modes). SE-theory[23] breaks this law and hence leads to artifact.

2.1 Real threshold conditions (*RTC*) for induced gamma-oscillation in *DOCLMP*

The parameter p of "reserved amplification" (*RA*) is introduced through a formal balance equation[1-9]

$$n\, \sigma_0\, \tau_2/\tau_1 = p\, (n\, \sigma + n'\, \sigma'), \qquad (16)$$

where $n = n_+ + n_-$ is a total density of working nuclei amount (*DWNA*) averaged over tooth volume; n_+ is *DWNA* for a level "+"; and n_- is *DWNA* for a level "-". This is a definition of *RA*. The value $L_0 = (n\sigma + n'\sigma')^{-1}$ is length of non-resonant losses in substance of tooth. Appropriate value in *DOCLMP* equals $2L_0$. Formally $RA = (\tau_2/\tau_1) n \sigma_0 L_0$ is a gain on length L_0. The definition *RA* (16) is only a handy combination of basic values and isn't a real balance equation: $n_+ < n$ and the induced cross-section reach limit $(\tau_2/\tau_1) n \sigma_0$ only at time $t >> \tau_2$[16,27]. *RA* is estimated from a complex of conditions below. By (16) *RA* has a maximum $p_m = p_0\, \tau_2/\tau_1$ where $p_0 = \sigma_0/\sigma = 888$ for ^{56}Co. Another basic value is a density n' of host-atoms. For a diamond $n' = 1.76\ 10^{23}\ cm^{-3}$. The relative impurity concentration n/n', a value ψ, total length L of *DOCLMP*, relative length $y = L/2L_0$, amount of diffraction modes $\boldsymbol{m}$, all data in **1.1** are the departure values in estimates. Then the *interim values* are derived: *RA*; cross-size $\boldsymbol{d}$ of *AM*; volume of *AM* $\boldsymbol{V = d^2L}$ (for a square form of *AM*-cross-section); solid angle $\boldsymbol{\Omega}$ of diffraction mode: total number $\boldsymbol{N_0 = nV/2}$ (half of comb-like AM is empty) of working nuclei; resonant cross section $\boldsymbol{\sigma_0}$, i.e.

$$\psi = (n/n')/((n/n') + (\sigma'/\sigma));\ L_0 = (1-\psi)/(n'\sigma');\ L = 2yL_0;\ p = \psi\, p_0 \tau_2/\tau_1;\ d = (m\lambda L)^{1/2};\ V = 4\,(L_0 y)^2\, m\lambda\,;\ \Omega = \lambda/L\,; \qquad (17)$$

$$N_0 = 2\,(m\lambda/n'\sigma'\sigma)\ \psi\,(1-\psi)\, y^2; \qquad (18)$$

$$\sigma_0 = (\lambda^2/2\pi) f' w/(1+\alpha). \qquad (19)$$

The number of γ-quanta arisen in the amplification of stimulated emission (*ASE*) at account of width-path effects is

$$N_A(p) = (N_S/y) \int_0^{\infty} e^{-x'}\, dx'\, [\exp[[\, pG(x') - 2\,]\, y] - 1] / [pG(x') - 2]. \qquad (20)$$

In usual case of a non-resonant detector the negative part «-2» of the «gain» **(pG−2)** contains two parts: the first ordinary part «-1» owing to the direct non-resonant losses and the **second equal but unusual part** «-1» owing to the non-direct influence of the same non-resonant losses but through the introduced above «Width-Path Effect» which particularly decrease the resonant cross-section.

Without WPE the «gain» would be **(pG−1)**. Here $x = t/\tau_1$; $N_S = (pym\tau_1/4\tau_2)\exp(-x_1)$ is a number of spontaneous γ-quanta emitted for all time in m modes in a spectral interval τ_2^{-1}; $\exp(-x_1) = n_+(0)/n$; $n_+(0)$ is *ELAN*-amount density at momentum $t = 0$. A value $pG(x)/L_0$ is a generalized induced gain. According to[27, 16, 10], a cross-section of induced emission $\sigma_i(t)$ equals to zero at the start momentum $t = 0$, when a resonant interaction (of *ELAN* and a gamma-radiation field) is switched. *The value of* $\sigma_i(t)$ asymptotically grows up to its limit $\sigma_i(\infty) = \sigma_o$ during time $\sim \tau_2$. A correct formula for $\sigma_i(t)$ is not yet derived because of difficulties in transforming of complicated non-linear decisions of Maxwell-Bloch equations to cross-section concept. As a compromise, a simple approximate formula containing <u>all properties marked above</u> was suggested and used in works[3-5,7-9] for the quick valuations:

$$\sigma_i(t) = (1-\exp(-t/\tau_2))\,\sigma_i(\infty). \tag{21}$$

Hence a stationary formula $p/L_o = (n_+ - g\,n_-)(\tau_1/\tau_2)\sigma_o$ for induced gain need be transformed to the next more complex form

$$pG(t)/L_o = n_+(t)\,\sigma_{+-}(t) - [n_-(0)\,\sigma_{-+}(t) + \int_0^t n_+(t')\,\sigma_{-+}(t-t')\,d(t'/\tau_1)\,]. \tag{22}$$

Here $\sigma_{+-}(t) = \sigma_{+-}(\infty)\,(1-\exp(-t/\tau_2))$ is $\sigma_i(t)$ for emission from "+" to "-" state; $\sigma_{+-}(\infty) = (\tau_2/\tau_1)\sigma_o$ is a limit for $\sigma_{+-}(t)$ at infinity great time. By analogy $\sigma_{-+}(t) = \sigma_{-+}(\infty)\,(1-\exp(-t/\tau_2))$ is $\sigma_i(t)$ for the transition from "-" to "+" state; $\sigma_{-+}(\infty) = (\tau_2/\tau_1)g\sigma_o$ is a limit for $\sigma_{-+}(t)$ at infinity time. In common case a value g can be different from $(2j_++1)/(2j_-+1)$. E.g., $g = 0$ in case of ideal *AWI* (ch.3); $g = 1$ in case of non-degenerated working levels. The nuclei arisen spontaneously in a lower state "-" at momentum t' are <u>dephased</u> at this time-point t'. So at $t > t'$ a phasing time t_ϕ of these nuclei (or time of growing of its absorption cross-section) is $t_\phi = t - t'$. The value $n_+(t')\,d(t'/\tau_1)$ is a number of "new" nuclei in state "-" in the time-interval dt'. In case of weak generation the populations $n_+(t)$ and $n_-(t)$ are

$$n_+(t) = n_+(0)\exp(-t/\tau_1),\quad n_-(t) = n_-(0) + \int_0^t n_+(t')\,d(t'/\tau_1). \tag{23}$$

A time-dependent factor $G(t)$ of induced gain function is transferred to the form (25) at a formal denoting (24):

$$\exp(-x_1) = n_+(0)/n;\ n = n_+ + n_- = const;\ n_- = (1-\exp(-x_1))n\,; \tag{24}$$

$$G(t) = (1-\exp(-x\tau_1/\tau_2))\,(\exp(-x_1 - x) - g) + g\exp(-x_1)\,(e^{-x} - \exp(-x\tau_1/\tau_2))\,/\,(1-(\tau_2/\tau_1)); \tag{25}$$

or else (see below) at denotations $\mu = e^{-x}$ and $\zeta = (\tau_2/\tau_1)$ ones have

$$G(t) = \mathbf{G}(\mu) = (1-\mu^{\zeta})\,(\mu\,\mu_1 - g) + g\,\mu_1\,(\mu - \mu^{\zeta})/(1-(1/\zeta)) \tag{25\#}$$

Note that the limit of $G(t)$ at $\zeta = (\tau_2/\tau_1) \to 1$ is a function $\mathbf{Lim\{}G(t)\ \mathbf{at}\ \tau_1/\tau_2 = 1\mathbf{\}} = G_{lim}(t)$ estimated as

$$G_{Lim}(t) = (1 - e^{-x} + gx)\exp(-x_1 - x) - g\,(1 - e^{-x}). \tag{25a}$$

Here (25a) corresponds to a particular case $\tau_1 = \tau_2$. <u>The decisions (25), (25a) satisfy for all initial and limit conditions.</u> The further analysis is based on the approximation of $G(t)$ by a quadratic form $G(\mu) \approx G_m - (\mu - \mu_o)^2 K$, where $\mu = e^{-x}$. The values G_m, μ_o, K depend on basic parameters τ_1/τ_2, g, $\exp(-x_1)$. Poisson's formula leads to

$$N_A(p) \approx (\pi p/yK)^{1/2}\,(m/4)\,(\tau_1/\tau_2)\exp(-x_1)\,\{\{\exp[(pG_m - 2)y] - 1\}\,/\,(pG_m - 2)\},\ p > p_{thr} = 2/G_m. \tag{26}$$

Here the negative part «− 2» of the «gain» **(pG$_m$ − 2) contains two parts: the part** «− 1» owing to the direct non-resonant losses and the another equal part«− 1» owing to the non-direct influence of the same non-resonant losses but through the introduced above «width-path» effect action. Eq.(26) is approximately valid **[1] at $(pG_m - 2)y > 0.5$ and contains <u>threshold condition for *ASE*:</u> $p > 2/G_m$. The more precision expression at **(pG$_m$ − 2) < 5** is omitted in this short report but will be published in the other more special work devoted only to the induced radiation. The roots of *equation* $G(\mu) = 2/p$ are $\mu_+(p) = \mu_0 + \Delta(p)$; $\mu_-(p) = \mu_o - \Delta(p)$, where $\Delta(p) = [(G_m - (2/p))/K]^{1/2}$. The factors «*2*» *instead of* «*1*» in (26) are due to the above <u>Width-Path Effects</u>. The start-time for γ-lasing is $t_+ = -\tau_1 ln\mu_+$. The end-time for γ-lasing is $t_- = -\tau_1 ln\mu_-$. At $t < t_+$ and at $t > t_-$ γ-lasing is absent. Time-interval of *ASE*-generation is $t_+ < t < t_-$ with duration $t_G(p) = t_- - t_+ = \tau_1 ln(\mu_+/\mu_-)$ and with a maximum of intensity at $t = t_m = -\tau_1 ln\mu_o$. Eqs.(20), (26) with $p = \psi p_0\tau_2/\tau_1$ give an upper limit of N_A. The substitution of decision p' *of equation* $p' = p\,t'_G/2\tau_2$ (instead of p) to (20), (26) gives a lower limit for N_A. Here $t'_G = t_G(p')$. Factor $t'_G/2\tau_2$ **over-accounts** a frequency band $\sim 2(t'_G)^{-1}$ of γ-pulse. The real value N_A is inside interval $N_A(p') < N_A < N_A(p)$. A peak energy

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** 1 In the SPIE-paper the eq. (26) was contained the incorrect factor *(m/8)* which was changed here into the true value *(m/4)*. This formula is approximately valid at $(pG_m - 2)y \geq 0.5$, i.e., in more wide region than the adequate formulae of Ref.[36]. The formula valid at $(pG_m - 2)y < 5$ is located in the main text of the Present Work and will be published in a further work which is in a progress.

flow I_p equals (at appropriate p or p') to the integrand of (20) multiplied by $E_\gamma/(d^2\tau_1)$. A peak saturation parameter $P_s = \tau_2\sigma_o I_p/E_\gamma$ is also used below.

Numerical examples. According to data of **1.1** there are the next values: $\tau_1/\tau_2 = 1.1$; $exp(-x_1) = 0.9$; $n/n' = 5\ 10^{-3}$; $\sigma'/\sigma = 4.7\ 10^{-3}$; $\psi = 0.515$; $L = 0.321$ cm; $y = 0.329$; $d = 3.8\ 10^{-5}$ cm; $p = 416.5 >> p_o = 2/G_m = 14.5$, p_o is a threshold. So it is a super-threshold γ-lasing. Note, that necessary short period $t_i \sim 10^{-8}$s of *ELAN*-implantation is in touch in SPTEN-method[2-9]. Besides, the prompt shatters with $t_i \sim 10^{-12}$ s could be created[1,2]. Other parameters are: $G_m = 0.138$; $\mu_o = 0.705$; $K = 1.586$; $\Delta = 0.290$; $\mu_+ = 0.995$; $\mu_- = 0.415$; $t_+ = 5\ 10^{-3}\tau_1 = 7.6\ 10^{-8}$s; $t_- = 0.879\tau_1 = 1.33\ 10^{-5}$s; $t_m = 0.35\ \tau_1 = 5.3\ 10^{-6}$s; $t_G = 0.874\tau_1 = 1.32\ 10^{-5}$s; $p' = 200$. The γ-lasing pulse characteristics are: $10^3 < N_A < 1.3\ 10^7$; $5\ 10^{-12} < N_A E_\gamma < 6\ 10^{-8}$ J; flux $F = N_A/d^2$: $10^{12} < F < 10^{16}$ cm^{-2}; $3\ 10^{-3} < FE_\gamma < 40$ J/cm^2; mean energy flow $I = F E_\gamma/t_G$: $230 < I < 3.0\ 10^6$ W/cm^2; $2\ 10^3 < I_p < 4\ 10^7$ W/cm^2; solid angle of mode is $\Omega = \lambda/L = 1.37\ 10^{-8}$ rad^2; brightness: $1.5\ 10^{10} < I/\Omega < 2\ 10^{14}$ W/cm^{2}rad^2; $2\ 10^{11} < I_p/\Omega < 3\ 10^{15}$ W/cm^{2}rad^2; $10^{-5} < P_s < 0.2$; $16 < N_S < 34$. The ratio "signal to noise": $60 < N_A/N_S < 4\ 10^5$ is more than sufficient for the experimental demonstration *of* γ-lasing.[2-5] A total number of working nuclei in *AM* is $N_o = 2\ 10^{11}$, i.e., less by 2-3 orders than amount of *ELAN*, which can be put into AM owing to SPTEN-method. Efficiency of γ-lasing in this case: $10^{-8} < N_A/N_o < 10^{-4}$. More effective results are at further increasing of concentration n/n'. E.g., at $n/n' = 0.01$ and the same $N_o = 2\ 10^{11}$ the values are: $L = 0.227$cm; $y = 0.352$; $d = 3.2\ 10^{-5}$ cm; $p = 549.5$; $t_G = 0.884\ \tau_1$; $p' = 265$; $4\ 10^4 < N_A < 3\ 10^{10}$; $4\ 10^{13} < F < 3\ 10^{19}$ cm^{-2}, that is less than its *p*-pulse limit[1] $F_{lim} = (p-1)/(\sigma_0\tau_2/\tau_1) \approx 5\ 10^{20}$ cm^{-2}; $0.2 < FE_\gamma < 10^5$ J/cm^2; $10^4 < I < 10^{10}$ W/cm^2; $2\ 10^5 < I_p < 2\ 10^{11}$ W/cm^2; $10^{13} < I_p/\Omega < 10^{19}$ W/cm^{2}rad^2; $10^{-3} < P_s < 660$, and I_p needs be decreased; $26 < N_S < 53$; $1.5\ 10^3 < N_A/N_S < 5\ 10^8$; $2\ 10^{-7} < N_A/N_o < 0.13$, i.e. a high efficiency could be gotten. It is very difficult to keep $\tau_1/\tau_2 \cong 1.1$, because at $n/n' > 0.005$ clustering of atoms leads to a strong line-broadening. These results could be corrected by accounting of noise, saturation, etc.

2.2 Real threshold conditions for the super-fluorescent (super-radiant) gamma-oscillation on base of the approximate theory in case of the strong varied length of Bloch's vector.

The decision[31] for the projection R_3 of Bloch's vector R had been generalized (1995,1998, Karyagin) for non-keeping R:[3,33]

$$R_3 = R\,(R - e^{\varphi+\varphi'})/(R + e^{\varphi+\varphi'}). \qquad (27)$$

Here $R = R'\,D_{ph} - (\tau_{mod}/\tau_2)$ is the length of *effective time-dependent Bloch's vector*; $R' = (ze^{-x} - g)N_o$ is a *time-dependent* ordinary inverse population in AM *generalized on common case of arbitrary nuclear state degeneration*, see **2.1.** Value R' depends on $x = t/\tau_1$ and $z = (1 + g)\exp(-x_1)$. Factor $D_{ph} = 1 - (1 + y)e^{-y} = (\beta/y^2)$ is an effectively phased relative part of all nuclei in the active medium **at the totally reliable event** that the spontaneously emitted γ-quanta are emitted in one axial generation mode, here $y = l/2L_0$. Values p, w, f', α, τ_1, τ_2, y, x, etc. see in **2.1.** Time τ_2 depends on length L', see Width-Path Effect in the beginning of **sec.2** and in **2.1**. The factor D_{ph} accounts the loss of photons from phasing process. That loss is owed to *scattering* or *non-resonant absorption* in AM. The speed of transitions $\tau_{mod}^{-1} = (1/2)\,(\Omega/4\pi)wf'(\tau_2/\tau_1)/(1+\alpha)\tau_1$ is the probability (in s^{-1}) of **the event above** that the γ-quantum is spontaneously emitted just in the axial generation mode. The factor 1/2 accounts the two polarizations; the solid angle of the first diffraction mode is $\Omega = \lambda/L$. The length $L = 2L_0\,\nu$ in case of a dispersed active medium is twice in a comparison with the usual active medium; the resonant cross-section averaged over all polarizations, directions and HFS-components is $\sigma_0 = (\lambda^2/2\pi)\,(w\,f'/(1+\alpha))\,(\tau_2/\tau_1)$; the formal gain factor $p = n\,\sigma_0\,L_0\,(\tau_2/\tau_1)$, see sec.2.1; the square of the transverse section of the active medium is $a_1^2 = \lambda L$; the volume of the active medium is $V = a_1^2\,L$; the total number of work nuclei (exited and non-exited ones together) $N_0 = (1/2)nV$ because the dispersed active medium is a half-empty one. The accounting of all relations above leads to the simple equivalent form $(1/\tau_{mod}) = (\nu\,p\,/\,4\,N_0\,\tau_1)$. Hence $\tau_{mod} = (4N_0\tau_1/\nu p)$ is the time of the spontaneous emission per one nucleus into the generation mode; note that $\tau_{mod} >> \tau_1$. The selection of photons for phasing in tight band $1/\tau_1$ is accounted in τ_{mod}^{-1} by the factor τ_2/τ_1. *Such factor is absent in more simple old formulas*[10,32]. *Because of it that old simple formulas* ***overestimate*** *SF-part in γ-lasing.* The main term of dephasing loss τ_{mod}/τ_2 is introduced in accordance with work[32]. It is necessary to fulfill the threshold condition $R'|_{t=0} > \tau_{mod}/(\tau_2 D_{ph})$, which at $D_{ph}=1$ coincides with Andreev's condition[32,10]. A number of effectively phasing "priming" photons for a time t is

$$\varphi = \int_0^t (R/\tau_{mod})\,dt = \int_0^t ((R'D_{ph}/\tau_{mod}) - \tau_2^{-1})\,dt. \qquad (28)$$

The "feedback" phasing addition from the super-fluorescent pulse in axial mode is

$$\varphi' = \int_0^t (\tau/\tau_0)\,I_{SF}\,dt = \int_0^t (I_{SF}/\tau_0)^{1/2}\,dt, \qquad (29)$$

where width τ^{-1} is a logarithmic derivation of function I_{SF} and $\tau_0^{-1} \equiv w/(1+\alpha)\tau_1$ is a radiation width. So $\tau^{-1} \approx (\tau/\tau_0)I_{SF}$ and the integrand in (29) is proportional to $I_{SF}^{1/2}$. This procedure (1995,1998,Karyagin) is approximate equivalent of averaging of resonant interaction "radiation-ELAN" over a time-depending frequency distribution of γ-pulse, evaluated as a Fourier from

pulse-form cut after momentum t. In a derivation $\mathbf{dR_3/dt = C_1 + C_2 + C_3}$ the term $\mathbf{C_1 = - R\,(R^2 - R_3^2)/(2\tau_{mod})}$ coincides with a right part of standard Bloch's equation. By analogy with[31] it gets

$$I_{SF} = (R^2 - R_3^2)/(2(g+1)\tau_{mod}) = 2R^3\, e^{\varphi+\varphi'} / [(g+1)\,(R + e^{\varphi+\varphi'})^2\, \tau_{mod}]. \tag{30}$$

Term $\mathbf{C_2 = dR/dt \equiv dR'/dt}$ is a natural addition to C_1 from inverse population decay and needs to be adopted in generalized Bloch's equation. Term $C_3 = -(1/2)\,(1 - (R_3/R))^2\, dR/dt$ has no apparent nature and can be understood as a deflection from exact equation $\mathbf{dR_3/dt = -(R^2 - R_3^2)\,R/(2\tau_{mod}) + dR/dt}$. At $x < x_c$ a relation $|C_1 + C_2| > |C_3|$ is valid; $\mathbf{x_c}$ is *a root of equation* $\mathbf{R'(x) = 0}$. An approximate decision (26) satisfies *to initial condition* $R_3(0) = R(0)$ *and to asymptotic condition* $R_3(\infty) = -R(\infty)$. A *maximum* of function I_{SF} is achieved in point $x = x_m$, in which $\mathbf{R(x) = e^{\varphi(x) + \varphi'(x)}}$. The analysis leads to the next algorithm in order to estimate the amount of γ-quanta in a super-fluorescent (super-radiant) pulse.

I. To introduce the three parameters which are independent on the relative length $y = L/2L_0$

$\mathbf{A_1 = (p/4)\,z\,;\ A_2 = (p/4)\,g\,;\ A_3 = 4\,N_{00}/p}$ where $\mathbf{N_{00} = N_{00}/y^2} = 2(m\lambda/n'\sigma'\sigma)\psi\,(1-\psi)$, see part **2.1**.

II. To estimate the argument *y* and its functions

$\mathbf{(\beta/y) = [1 - (1+y)e^{-y}]/y\,;\ G_1 = (\beta/y)\,A_1;\ G_2 = (\beta/y)\,A_2 + (\tau_1/\tau_2)\,;\ K' = y\,A_3}$. Note that $K = (4N_0/yp)$ but $N_0 = y^2 N_{00}$.

III. To introduce the argument $x = t/\tau_1$ and its functions $R(x) = K\,[G_1 e^{-x} - G_2]$; $\varphi(x) = G_1\,(1 - e^{-x}) - x\,G_2$; $\xi_1(x) = e^{\varphi}$.

The region of x in which $R(x)>0$ and $\varphi(x)>0$ is determined by the conditions $x < x_c \equiv \boldsymbol{ln(G_1/G_2)}$ and $(G_1/G_2)(1-e^{-x}) > x$

IV. The majorant for the formula (29) $\varphi'_{maj} = 2\ln[1 + (R/\xi_1))/2e] - 4(\xi_1/R) > \varphi'$ leads to the simple approximate results $\xi_2(x_m) < e^{\varphi'(x_m)maj} \cong 31.5$; $R(x_m) < R(x_m)_{maj} \cong \xi_1(x_m)\,31.5$; $\xi_1(x_m) \cong \xi_1(x_c)$; $x_m = \boldsymbol{ln[G_1/(G_2+(R/K))]}$;

$$N_{SF} < N_{SF\,maj} \equiv N_{00}\,\xi_1(x_m)\,\xi_2(x_m) \equiv (1 - e^{-y})\,y^{-1}\,(1+g)^{-1}\,\xi_1(x_m)\,\xi_2(x_m). \tag{31}$$

Numerical example for Co^{58}: $E_\gamma = 28.1$KeV; $g=9/11$; $\exp(-x_1) = 0.9$; $\tau_1/\tau_2 = 1.1$; $z = 1.636$; $p = 416$; $N_{00} = 1.85\ 10^{12}$; $A_1 = 170$; $A_2 = 85.1$; $A_3 = 1.78(10)$. *In case* $n/n' = 0.005$, $n = 8.8\ 10^{20}\ cm^{-3}$; $N_o = 3\ 10^{11}$; $y = 0.402$; $\beta/y = 0.154$; give: $G_1 = 26.3$; $G_2 = 14.2$; $\mathbf{K'} = 7.16\ 10^9$; $x_c = 0.616'326'97$; $x_c - x_m < 10^{-8}$; $\xi_1 = 28.5$; $\xi_1\xi_2 = R = 900$; $N_{SF} < N_{SF\,maj} = 400$; $N_{ASE} = 9.6\ 10^8$; $N_{SF}/N_{ASE} = 4.2\ 10^{-7}$; $N_{spont} = 42$. Calculations show that *in the induced super-threshold regime* $N_{SF} << N_A$ at the same parameters of active medium for SF and ASE. Only for a weak near-threshold regime (when $N_{SF} \approx 10$) could be $N_{SF} > N_A$, i.e., so called "weak SF"[32]. The results of ch.2 are more realistic than ones of simple theories.

3. SELECTIVE RESONANT PUMPING CASE

3.1 Resonant activation of ELAN

The SPTEN secures the most soft effects of both *radiation and heat* on AM. On the further places towards soften action on AM are all cases *when parents of ELAN are preliminarily sited in AM.* That parents could be transformed into ELAN by many methods of exposure of parent-nuclei by fluxes of different (non-charged or charged) particles from the various sources[1-10,16]. Among this manifold (without SPTEN) the methods of selective resonant pumping[30,1,8,9,16] (SRP) have the most big efficiency factor and could provide a pumping with rather soft heat-radiation AM-regimes. But towards soften action on active medium SRP is only on the second place after SPTEN among all manifold of γ-lasers.[4,5]

In case of SRP a beam-flux of resonant γ-quanta $F \approx 27/\sigma_o \approx 3\ 10^{18}\ cm^{-2}$ is necessary in order *to create a marked amount of ELAN in AM.* Here the time-dependence of σ_i, see eq.(21), and duration of SRP-pulse-pumping $t_p \approx 0.1\,\tau_1$ were accounted. Due to resonant absorption this flux is a fast decreasing function of length. if a flux-direction coincide with a *longitudinal* direction of AM. So in this case AM could be created only when $L << L_o$. But the ratio $y = L/L_o << 1$ is not effective for γ-lasing, see **2.1** and **2.2.** Hence the *transversal* or *interim* type of SRP is necessary. In interim case a part of AM cold be in the sufficiently good thermal conditions. But a rest part of AM could be heated so as in a *hard transversal pumping.* So the latter is sufficient to regard. A typical case of ^{58}Co in diamond, see **1.1**, is regarded below without loss of proof-community.

A region of crystal-cooler exposed by SRP-beam has cross dimensions $d \times L \approx 4\ 10^{-5}$ cm $\times$ 0.32 cm and longitudinal size $L_h > (\sigma'n')^{-1} \approx 1$ cm. It is a rectangular plate with sizes $L_h \times L \times d \approx 1\text{cm} \times 0.32\text{cm} \times 4\ 10^{-5}$cm submerged in a crystal. The heat-release in such exposed "plate" (owed to photo-effect on host atoms) is $q_p \approx F\sigma' E_\gamma n'/t_p \approx 10^{11}$ J/cm^3. So $q_p \approx q$, see eq.(1), but condition (1) is strongly broken, because transversal (relative to main heat-flux from AM) sizes are big: $L_h, L >> \Lambda_e, \Lambda_{ph}$. With use of *self-consistent method*, see 1.2, the quasi-temperature of that "plate" and around AM $T_p \approx 700$ - 750K is estimated. It decreases paths $\Lambda_e \approx 5.9\ 10^{-6}$ cm $<<$ d, $\Lambda_{ph} \approx 2.8\ 10^{-6}$ cm $<<$ d. As a result the speed of energy exit from AM is suppressed by factors $f = \exp(-d/\Lambda)$: $f_e = 0.0015$ (for electrons) and $f_{ph} = 10^{-6}$ (for phonons). **So SRP adiabatically isolates AM from cooler and AM explodes before γ-lasing**. The situation can be changed by Borrmann effect[1,2,10,16,17] at coupling factor $K = 10^{-6} - 10^{-7}$. Note, that in fast pumping and γ-lasing ***all AM of other types (plasma, gas) are always adiabatically isolated***.

3.2 Schemes of amplification "with" and "without" inversion

Note that a selective pumping needs to use schemes for inversion[1,2,10,11] or for amplification without inversion[1,2,10,12] (AWI). But (see **1.2.1.6**) *the active medium of gamma-laser differs from the substance of the Moessbauer sources with the significant concentration of the charged carriers: electrons and holes*[2-5,7-9]. Its typical values are about 10^{16}-10^{18} cm^{-3} (e.g., for ^{58}Co/Di). At this condition all electronic and nuclear hyperfine structure (HFS)-levels are in strong stochastic motion and are mixing

(see **1.6**). Hence it is important to provide the *steadiness of inversion and AWI schemes to the charge exchange* (**CE**). AWI-schemes[1,2] (1980,Karyagin) are steady to CE. Its base is stability of electron-state configuration in some superposition of optical fields to stochastic influence of atomic environment on HFS[14,15]. Sorry, a visual model in that class[1,2] is stable to recharging only for "crystal-chemical narrowing"[15]. This simple AWI is based on selective induction (SI) of optical transition only for atoms (ions) with working nuclei in ground state (WNGS). At such SI the electronic state (ES) of atoms (ions) with ELAN remains unchanged, whereas the ES of atom (ion) with WNGS is converted into a mixture state (e.g., Ruby state) dependent on dynamics of transitions.[1,2] As a result the gamma-absorption line is *shifted in frequency* relative to the γ-emission one. So AWI arises[1,2]. *Note, that at 1980 the word "AWI" was not exist. Instead of it was used the term* ***"optical division" in time*** *of single pumping process into two: excitation of nuclei and damping of self-absorption*[1,2].

4. DIFFICULTIES OF NON-SOLID GAMMA-RAY LASERS

The solid model[1-9,14,15,19] was foregone with testing of non-Moessbauer AM creation on base of *Marcuse's effect*[29]. Some difficulties revealed in that way need be accounted in modern researches, e.g.[20,26,35].

For γ-lasing in solid plasma (SP): The ends of AM are spreading more quickly than its middle. *A speed-difference between the ends is* $|\Delta V| > 10^7$ *cm/s.* For $E_\gamma \sim 100$ keV it leads to Doppler width $\Gamma_D \sim |\Delta V|\ \omega/c > 10^{17}\ c^{-1}$ and to unreality of γ-lasing on SP (cf.,**1.3**). *Besides*: The losses of γ-lasing owing to its scattering on free electrons of plasma needs to be accounted.

For beam γ-lasing (BGL). There is *a row of steps1-9* in order to qualitatively estimate a beam γ-lasing (BGL).

Step1. Suppose, that gas-AM is somehow cooled. Let at time t = 0 all atoms in beam have equal speeds. But it is impossible to transform *mixed* ***ionized*** *atomic beam* in a gas-lattice with equal inter atomic gaps along AM-axis. The gaps r are spread around $r_{av} = n^{-1/3}$ with dispersion $|\delta r| \sim r_{av}$. In gas-AM electrons (see below) are adhered and so Debye shielding is not valid at fast resets. Interactions of atoms and ions are not strongly shielded in such gas even at *formal* Debye radius $r_D << r_{av} << r$: interaction energy U(r) is random and dispersion of axial atomic speed for t > 0 is $\Delta V_{\|} \approx (t/M)\ |d^2U/dr^2|_{av}\ |\delta r|$. Account of Doppler broadening condition $V_{\|}\ \omega/c < 1/\zeta\tau_1$ leads to

$$|d^2U/dr^2|_{av}\ t\ |\delta r| < Am_pc/(\tau_1\omega\zeta), \tag{32}$$

where $\zeta \sim 1$ for atomic beams, but $\zeta << 1$ for free nuclei beams (see *step6*); $t \approx \tau_1$ is a time of acceleration of marked atom in field of one nearest neighbor. Here m_p = **1.67 10^{-24} G** is a proton-mass; A is atomic mass-number; $\omega = 1.52\ 10^{18}\ E_\gamma\ s^{-1}$ is a frequency of γ-quantum (E_γ is in keV). The gas-AM is saturated by ions, because internal conversion initiates creation of Auger electrons ~ 10 - 10^2 and secondary ones ~ 10^2 - 10^3 which adhere to atoms or to walls. At $\tau_1 < 10^{-4}$ s the concentration of "+" and "–" ions in gas-AM is $C_i > 10^{-3}$. For a free nuclei beam $C_i = 1$. The polarization by ions enhances interaction of atoms with environment. Averaging over neighbor pairs: atom-atom, ion-ion, atom-ion gives $|d^2U/dr^2|_{av} \approx e^2nK_i$. Here e is elementary charge 4.8 10^{-10} CGSE, **n** is a density-amount of atoms, $K_i \approx (10^{-1} - 10^{-2})\ C_i$. Together with (32) it gives:

$$(K_i)^{3/2}n < 5\ 10^{-20}\ [A/\zeta E_\gamma\tau_1^{\,2}]^{3/2}, \text{ if } \tau_1 < t_{av};\quad (K_i)^3 n < 5\ 10^{-64}\ [A^{1/2}/\zeta E_\gamma\tau_1]^3, \text{ if } \tau_1 > t_{av}. \tag{33}$$

For $A \approx 200$, $E\gamma \approx 10$ keV, $\tau_1 \approx 10^{-8}$ s, $\lambda \approx 10^{-8}$ cm, $\sigma_o \approx 10^{-18}$ sm^2, $K_i > 10^{-5}$ a gas-density is $n < 10^{14}$ sm^{-3}. Condition $\sigma_o nL \approx 100$ (see ch.2) leads to $L \approx 10^6$ cm, $d = (\lambda L)^{1/2} \approx 0.1$ cm, $N_o = nd^2L > 10^{18}$. It is difficult case. {For SPTEN (see **2.1**) the appropriate values are A = 58; $E\gamma$ = 28.1 keV; τ_1 =1.51 10^{-5} s; $n \approx 10^{21}$ cm^{-3}; n' = 1.76 10^{23} cm^{-3}; $d \approx 3\ 10^{-5}$ cm; N_o = 2 10^{11}; $T_{AM} \approx$ 30 K; $N_A = 10^4 - 10^{10}$.}

Step2. *Laser cooling*[35] *uses rarefied non-ionized almost ideal gas* when a force acting on any atom from cooling optical field (COF) is *regular (non-chance)* function **F(r,V)** of its velocity **V** and position **r**. E.g., if $\mathbf{V}_i = \mathbf{V}_j$, $\mathbf{r}_i = \mathbf{r}_j$ for any i^{-th} and j^{-th} atoms, then in ideal gas $\mathbf{F}(\mathbf{r}_i,\mathbf{V}_i) = \mathbf{F}(\mathbf{r}_j,\mathbf{V}_j)$. In case of ionized gas ($C_i > 0.001$) the i-th and j-th atoms are differ owing to various charges or different Stark-effect in field of environment. So $\mathbf{F}(\mathbf{r}_i,\mathbf{V}_i) \neq \mathbf{F}(\mathbf{r}_j,\mathbf{V}_j)$ and **F(r,V)** is a *chance* function. A moving for a majority of atoms at force $\mathbf{R} = -\nabla U(\mathbf{r}_i) + \mathbf{F}(\mathbf{r}_i,\mathbf{V}_i)$ is a long auto-oscillations different from fast damping in ideal gas. So *laser cooling of a real gas-AM is strongly decelerated.*

Step3. The recoil force due to spontaneous emission of optical photon is about $F_{sp} \sim 10^{-15}$ dynes and approximately equals to the chance force $F_{ch} = |dU/dr|_{av}$ in gas at n ~ 10^{14} cm^{-3}, see *step 1*. It gives a hope of laser cooling, i.e.. damping of axial velocity $V_{\|} \sim c/\omega\tau_1 \sim 0.2$ cm/s with COF-power $q' \sim 10^4\ MnV_{\|}^2/(2\tau_1) \sim 10^{-1}$ W/cm^3 and flux $J' \sim q'd \sim 10^{-2}$W/cm^2. Factor ~ 10^4 accounts that *energy transferred from gas to COF is small part of COF*[35].

Step4. *A heat release from internal conversion* (**HRFIC**) in case above is $q \sim nE_\gamma/\tau_1 \sim 10^7$ Wcm^{-3} and *flux-COF* needs be $J' \sim 10^4 qd \sim 10^{10}$Wcm^{-2}. HRFIC is the main block in gas-AM ***because of its adiabatic isolation*** (cf. **3.1**). For arbitrary *n* (in cm^{-3}) $L \sim 10^{20}\ n^{-1}$ cm, $d \sim 10^6 n^{-1/2}$ cm, $N_o \sim 10^{32}\ n^{-1}$, $q \sim 10^{-7}n$ Wcm^{-3}, $J' \sim 10^4 qd \sim 10^3\ n^{1/2}$Wcm^{-2}. So *if* L~100 cm, *then* $n \sim 10^{18}$cm^{-3}, $d \sim 10^{-3}$cm, $N_o \sim 10^{14}$, $q \sim 10^{11}$Wcm^{-3}, $J' \sim 10^{12}$Wcm^{-2}, i.e., the cooling conditions are more hard than in solid.

Step5. Gas-AM has an initial heat energy ~10 - 10^5 eV per atom (recoil-energy in nuclear reaction for ELAN-creation) or $Q_i \sim (10^{-18} - 10^{-14})$ n J/cm^3. This energy need be taken by *COF* for time ~ τ_1. So additional flux of *COF* needs be $J'' \sim 10^4 Q_i d/\tau_1 \sim (1 - 10^4)\ n^{1/2}$ Wcm$^{-2} \sim 10^9 - 10^{13}$ Wcm^{-2}. So *steps 4-5* give a no go.

Step6. In case of free nuclei beam: K_i=1, $\zeta \sim \sigma_{fn}/\sigma \sim (10^{-10} - 10^{-12})Z^2 \sim 10^{-6} - 10^{-8}$, where $\sigma_{fn} \sim (e^2Z^2/Am_pc^2)^2 \sim 10^{-32}Z^2$ cm^2 is Compton cross-section for *free nucleus*, Z is number of protons in nucleus, $\sigma \sim (10^{-22} - 10^{-20})$ cm^2 is a usual cross-section of

non-resonant losses, see ch.1,2. Hence condition (33) is changed into $n < (10^{-4} - 10^{-1}) [A/(\tau_1 Z)^2 E_\gamma]^{3/2}$ with *numerical results* ($A \sim 200$, $Z \sim 100$, see *step1*) : $n < (10^{16} - 10^{18})$ cm^{-3}, $L \sim 100/\sigma_o n \sim 10^4 - 10^2$ cm, $d \sim (10^{-2} - 10^{-3})$ cm, $N_o \sim 10^{16} - 10^{14}$. It seems as eligible case. But it needs to account *step5*: $J'' \sim (10^8 - 10^{13})$ Wcm^{-2} supposing that efficiency of COF is the same for both: atoms and free nuclei. But it is not so: efficiency for free nuclei is less by many orders. So a real $J'' >> 10^{15}$ W/cm^2. It's no go again.

Step7. A dilution of free nuclei by free electrons (Z per nucleus) changes factor ζ into $\zeta' \sim Z\sigma_{fe}/\sigma \sim 1 - 10^{-2}$, where σ_{fe} is Thomson cross-section. Fast shielding by free electrons returns effective factor $K_i > 10^{-5}$ **with all rest results of step1**. Relativistic factor in ζ' don't change sufficiently these results.

Step8. Difficulties in steps 1 – 7 could be soften by use of MBE[3,5,6,19], which can decrease the values C_i, q, Q_i, J'' by some orders.

Step9. ***SPTEN is a hybrid of beam and solid g-lasers.*** In this hybrid the functions of gas-AM are separated in space: the initial stage (creation of ELAN and high inversion) is sited in a beam, but the further functions (generation, cooling) are cited in solid. The results (theory, methodology, trial, technique) in elaboration of BGL independently on its practice could be useful for SPTEN.

5. PROGRAM-CONCEPTION FOR DEVELOPMENT AND CREATION OF GAMMA-LASER

The *Concept* as a single complete regarding of ways for the experimental *feasibility* of γ-laser and a detailed *program for the gamma-laser materialization* are ready to experimental examination. Some topics of Concept are reflected in present work.

6. CONCLUSION

Model-SPTEN is feasible. For a long period (1980 – nowadays) it is steady to a plenty of difficulties. Such steadiness is based on main property of cold solids: quasi-particles (phonons, electrons, holes, *but not atoms!*) effectively provide the transferring of energy and charges. Another media have no such useful property. Many ways are revealed for experimental feasibility of γ-laser: devices for effective SPTEN-pumping on base of existing technique; modi to keep AM frozen during γ-lasing; effective nuclei-candidates with appropriate matrixes; theory and handy formulas for analyses of real threshold conditions, heat and radiation regimes; analyses of further difficulties in gas and plasma AM; hot micro plasma in cold AM; conditions for the collapse of working heterogeneous spectrum into one narrow line; amplification without inversion (AWI) and schemes with inversion steady against micro plasma; L'-effect (*with-path effect, WPE*) on time τ_2; prospect of high powerful γ-lasers[8,9]; usefulness of some results (MBE, DOCLMP) in nowadays practice, etc. It needs a wide collaboration in these fields.

7. ACKNOLEGEMENTS

Author express his gratitude to V.I.Gol'danskii for the support of present direction and R.V.Khokhlov, Yu.B.Khariton, A.A.Rukhadze, V.S.Letokhov, G.C.Baldwin, Y.M.Kagan, J.J.Carroll, C.B.Collins, A.N.Starostin, L.A.Rivlin for the discussions in divers times.

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27.12.99